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Performance Evaluation of Hap-Free Paint Strippers vs. Methylene-Chloride-Based Strippers for Removing Army Chemical Agent Resistant Coatings (CARC)

by John Kelley and Thomas Considine

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14. ABSTRACT
The U.S. Environmental Protection Agency intends to enact new National Emission Standards for Hazardous Air Pollutants (NESHAPs). One of these NESHAPs is expected to directly impact many of the Department of Defense organic coating stripping operations that involve methylene-chloride-based paint strippers. Overall, there are two chemical depainting processes that will be impacted: “manual” (brush-on, scrape off) and “immersion” (dip tanks). The purpose of this effort is to investigate HAP-free alternative chemical paint strippers as potential replacements for the methylene-chloride-based chemical strippers currently used in both processes. Historically, methylene-chloride-based strippers have been faster and more effective at stripping the MIL-P-46168 chemical agent resistant coatings (CARC) system than many alternatives. Therefore, finding a HAP-free chemical stripper that will minimally impact the U.S. Army depots throughput rate is an important consideration. This report compares the performance of methylene-chloride strippers vs. HAP-free alternatives in timed laboratory paint stripping experiments to remove four different CARC systems: MIL-P-46168, MIL-P-53039, and MIL-P-64159 Type I and Type II from both aluminum and steel substrates.

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1. Introduction

Methylene chloride is a widely used chemical solvent with a diverse number of applications. It was introduced as a replacement for more flammable solvents over 60 years ago and is commonly used in paint removers and industrial adhesive applications (*1*). Methylene chloride (dichloromethane) is an organic solvent that is especially effective as a paint remover. However, overexposure can cause serious health problems. Like many organic solvents, methylene chloride can damage the brain, as well as the skin, lungs, and other organs. In addition, it has been shown to cause cancer in humans and laboratory animals (*2*). For this reason, the Occupational Safety and Health Administration reduced its allowable exposure limits from 500 ppm in an 8-hr time weighted average (TWA) period in 1971 down to 25 ppm TWA for 8 hr or a 125 ppm for shorter term exposure in a 15-min sampling effective in 10 April 1997 (*3*). Additionally, the National Institute for Occupational Safety and Health (NIOSH) recommends that exposure to methylene chloride in the workplace be limited to the lowest feasible limit and the American Conference of Governmental Industrial Hygienists (ACGIH) recommends a workplace exposure limit of 50 ppm averaged over an 8-hr day.

The effects of methylene chloride are not limited to the health implications caused in the workplace. It has also been identified as a Hazardous Air Pollutant (HAP) by the U.S. Environmental Protection Agency (EPA). In fact, the EPA will be introducing a series of new National Emission Standards for Hazardous Air Pollutants (NESHAPs) that will likely impact current operations within the U.S. Department of Defense (DoD) and industry as a whole. It is expected that one of these NESHAPs, specifically “Surface Coating of Defense Land Systems and Miscellaneous Equipment” will directly impact many of the Army’s chemical depainting operations that use methylene chloride (*4*). Since this NESHAP focuses specifically on organic finishing processes, the U.S. Army expects a number of their current operations to be impacted. One of the most significant ways these operations could be impacted may include compromising combat readiness by limiting or discontinuing current refinishing operations. Therefore the U.S. Army has initiated the Sustainable Painting Operations for Total Army (SPOTA) program. This program is aimed at keeping the effected operations and facilities operational and in compliance upon implementation of the upcoming NESHAP.

The U.S. Army Research Laboratory (ARL) has been tasked with identifying and evaluating HAP-free alternative paint strippers as a potential replacement for methylene-chloride-based strippers. One of the major obstacles in finding a suitable “drop-in” replacement for methylene chloride is that most HAP-free products have been known to have slower stripping times than those that contain methylene chloride. The overall strip time is an important consideration especially in the high volume operations typically found at U.S. Army depots. Finding a chemical stripping “process” that will maintain, as close as possible, the current throughput rate

at the depots is of utmost importance. Compounding the issue further is the U.S. Army's family of Chemical Agent Resistant Coatings (CARC). These coatings are, by their very nature, chemical resistant and are among the most difficult to remove by chemical means. The coating system is made up of an epoxy primer with a high solids polyurethane top-coat. Moreover, the various surface conditions and pretreatments used and the substrate alloys can also affect the coatings resistance to chemical strippers.

The Gap Assessment Report generated by Concurrent Technologies Corp. (CTC) and National Defense Center for Environmental Excellence (NDCEE) (*4*) identified three U.S. Army facilities as primary users of methylene chloride strippers: Anniston Army Depot (ANAD), AL; Corpus Christi Army Depot, TX; and Letterkenny Army Depot, PA. The majority of the methylene chloride coating removal process at Corpus Christi is done with a MIL-R-81294 Type I Class I stripper (*5*). The MIL-R-81294 contains phenol and sodium chromate as well as methylene chloride. This stripping operation is typically a multistage process. The stripper is brushed on and allowed to penetrate the coating for at least 2 hr. At the end of this dwell time, the coating is scraped off. Multiple applications are usually necessary to remove all of the coating. This is referred to as a "manual" process. Similarly, some of the "manual" processes performed at Letterkenny utilize a methylene-chloride-based stripper that conforms to Federal Specification TT-R-251J Type III, Class A (*6*). No methylene chloride immersion tank processes are in use at either Corpus Christi or Letterkenny.

The largest consumer of methylene chloride strippers within the U.S. Army is ANAD. ANAD has five immersion vats ranging from 1800 to 2200 gallons designated for use with a methylene chloride paint stripper. In this operation, various parts from battlefield tanks and other armaments are totally immersed in the methylene chloride solution at ambient temperature for up to 30 min. The stripper used in the immersion processes at ANAD conforms to specification MIL-R-81903A Type II Class II (*7*), and the major ingredients are methylene chloride, formic acid, surfactants, aromatic hydrocarbons, and wax. The wax acts as a floating barrier layer to help reduce the chemical emissions. ANAD uses nearly 20,000 gallons of this product which emits 50 tons of methylene chloride annually (*8*). To a far lesser degree, ANAD also performs the "manual" stripping operations using other methylene chloride products conforming to TT-R-251J.

ARL worked in cooperation with the depots to draft site-specific performance requirements and establish baselines by which to measure the effectiveness of the HAP-free strippers. Because of their large volume of work and size of the parts stripped, the requirements for HAP-free alternatives to methylene chloride in the immersion process were almost exclusively based on the requirements of ANAD. The primary requirements that an alternative stripper must meet to be considered for use at ANAD are as follows: (1) it must remove 100% of the coating in a 30-min immersion time; (2) it must meet NESHAP emission standards; (3) it must not create a health hazard that is excessively difficult to manage; (4) it must be available in large enough quantities to satisfy ANAD operations; (5) it must be cost effective; and (6) its maintenance must be manageable by the ANAD operations staff.

The “manual” stripping process performance requirements were somewhat more ambiguous. Letterkenny and Corpus Christi use different products and therefore their expectations for the strippers were different. Moreover, even with the use of a methylene chloride product, the “manual” process was much more time consuming. Dwell times ranged from 2 hr to overnight. However, to set some project metrics, ARL in conjunction with Aviation & Missile Command (AMCOM) developed a baseline performance criterion that is a function of the thickness of the coating being stripped.

The information presented in this report represents the results of laboratory performance evaluations of the HAP-free strippers vs. the baseline methylene chloride containing strippers. More testing is ongoing to further qualify the better performing HAP-free strippers using the U.S. Army Depainting Test Protocol (*9*).

2. Experimental Procedure

2.1 Sample Preparation

Aluminum alloy 2024-T3 and standard cold rolled steel plate were chosen as the substrate materials. All aluminum panels were treated with Alodine 600 chromate pretreatment and all steel panels were zinc phosphated prior to painting. The panels were painted according to a modified version of ASTM D6189-97 (*10*). Both aluminum and steel panels designated for solvent-borne CARC (MIL-C-53039 [*11*] and MIL-C-46168 [*12*]) were primed with epoxy primer MIL-C-53022B (*13*), and those designated for water-borne CARC (MIL-DTL-64159 [*14*] Type I and Type II) were primed with MIL-P-53030 (*15*). Multiple coating applications were used to achieve the final coating thickness. The layer colors were alternated between 686 tan and 383 green to make the stripping evaluations easier to quantify. A schematic of each of the CARC painted panels can be seen in figure 1. The top layer of the solvent-borne panels was tan while the water-borne panels were green.

2.2 Alternatives Selection

The Gap Assessment Report generated by CTC/NDCEE identified many HAP-free alternatives to methylene chloride for use in both the “manual” and “immersion” processes. The information presented in the NDCEE report also included the estimated strip times (as reported by the vendor) of many of the products. ARL used this information to select the alternatives to be included in its test matrix. Those that reported strip times of above 2 hr were not included. ARL also consulted with end users and other leaders in the paint and industrial chemical industry for their recommendations. Once all of this information was considered, a list of the candidate strippers was compiled and the manufacturers were contacted. The candidates for “immersion” stripping are listed in table 1, and the candidate strippers for the “manual” process are listed in table 2.

Table 1. Immersion process candidates.

Product Trade Name	Manufacturer	Process	Contents	PH
Gardostrip 7900Q	Chemetall Oakite	Trade Secret Alt.	Proprietary ingredients	3
Dip Strip	Back to Nature	NMP	N-methyl pyrrolidone	—
Safety Strip 5896	Brulin	NMP	N-methyl pyrrolidone (90%)	—
Envirostrip 1-S	Chem Marketing	NMP	N-methyl pyrrolidone (80%)	—
Envirostrip #2	Chem Marketing	NMP	Phenyl carbinol, hydrogencarboxylic acid (20%), aromatic petroleum dist. surfactant	—
Envirostrip #3	Chem Marketing	NMP	Propionic acid, N-methyl pyrrolidone (70%), dihydro furanone, tergitol	—
CEM 483WW23	Coral Chemical	NMP	N-methyl pyrrolidone	—
Greensolv 273D	Greensolve Inc.	NMP	Amide, pyrrole	6–8
Greensolv 274WL	Greensolve Inc.	NMP	Pyrrole alcohol, ethoxylated alcohols, ammonia	10.74
Aerostrip 5182	West Penetone	NMP	N-methyl pyrrolidone	11.6
RS 75	WSI	NMP	N-methyl pyrrolidone	—
A1 Strip 49	Coral Chemical	Hydrogen peroxide	Hydrogen peroxide	—
CEM 483WW32	Coral Chemical	Hydrogen peroxide	Hydrogen peroxide	—
A1 Strip/AD 3030	Coral Chemical	Hydrogen peroxide	Hydrogen peroxide	—
HT-2263	Eldorado	Hydrogen peroxide	Formic acid, oil, ethanolamine	—
PR 5044	Eldorado	Hydrogen peroxide	Hydrogen peroxide	—
K-Chem Strip III	K-Chem	Benzyl alcohol	Formic acid, benzyl alcohol	2
D-Zolve 15-33LO	Solvent Kleene	Benzyl alcohol	Alkyl methyl ester, petroleum naptha, benzyl alcohol, methyl phenyl ether	10.5
D-Zolve 298	Solvent Kleene	Benzyl alcohol	Benzyl alcohol, formic acid	2.1
D-Zolve 3703	Solvent Kleene	Benzyl alcohol	Dimethyl formamide	5.03
NPX	West Penetone	Baseline	75% methylene chloride, 25% formic acid	—
Methylene Chloride/H2O	NA	Baseline	Methylene chloride	—

Note: NA = not applicable.

Table 2. Manual process candidates.

Product Trade Name	Manufacturer	Process	Contents	PH
Multi-Strip	Back to Nature	NMP	N-methyl pyrrolidone (15–30%), dimethyl glutarate (25–40%), dimethyl adipate (10–20%)	—
Readstrip Hi-Perf	Back to Nature	NMP	N-methyl pyrrolidone (10–15%), dimethyl glutarate(30–35%), dimethyl adipate (10–15%)	—
Ultra-Strip	Back to Nature	NMP	N-methyl pyrrolidone (35–50%), dimethyl glutarate(20–35%), dimethyl adipate (5–20%)	—
Ardrox 2865	Chemetall Oakite	Benzyl Alcohol	Benzyl alcohol	6.0–7.3
Dorado 5051	Eldorado	Benzyl Alcohol	Benzyl alcohol, hydrogen peroxide	3.0–5.0
D-Zolve 15-33LO	Solvent Kleene	Benzyl Alcohol	Alkyl methyl ester, petroleum naptha, benzyl alcohol, methyl phenyl ether	10.5
D-Zolve 3703	Solvent Kleene	Benzyl Alcohol	Dimethyl formamide	5.03
D-Zolve 1220GEL	Solvent Kleene	Benzyl Alcohol	Benzyl alcohol, formic acid	2.1
Crest Strip #28	Crest	Baseline	Phenol, methylene chloride	—

2.3 Immersion Stripping Experiment

As previously mentioned, this effort focused on two chemical stripping processes commonly used at the U.S. Army depots: "immersion" and "manual." The immersion process employs stainless-steel vats or tanks of various sizes filled with chemical stripper. The parts are immersed in the stripper for a period of time, removed, and subsequently rinsed with water. This is typically done at ambient temperatures using methylene chloride based strippers. However, the manufacturers of all of the HAP-free candidates recommend that their product be used in heated immersion baths. The temperature range recommended by the manufacturers is between 150 and 170 °F. Therefore, the apparatus used for these experiments were stainless steel "mini" vats that were heated in a hot water tank similar to a steam table. The temperatures of the individual chemical strippers were monitored closely with a digital thermocouple to ensure that the strippers were used within the recommended temperature range (figure 2). Stainless-steel bars were positioned across the tops of the mini-vats to support and evenly space the test panels during immersion. The panels were immersed vertically exposing approximately 1/3 of the panel to direct contact with the stripper. The panels remained immersed for 30 min, then removed and immediately rinsed with deionized water.

2.4 Manual Stripping Experiment

The manual process requires the chemical stripper to be brushed or sprayed on and allowed to penetrate for a period of time. Because the manual process is performed in open air, and on surfaces that may be positioned vertically, the chemical is usually thickened. Figure 3 shows the test panels awaiting manual application of the chemical strippers. For this experiment, a prescribed test area was masked off on each panel. The chemical stripper was applied to the exposed area of the panel using a 2-in paintbrush. The amount of time the stripper is allowed to penetrate (dwell time) was dependent on the total paint thickness. The paint thickness varied by the type of CARC. The average thickness of the MIL-C-46168 was 10 mil while the MIL-DTL-64159 averaged 6 mil thick. The dwell time allowed for all manual strippers was derived from the CCAD requirement of 45 min per each 3 mil of paint. At the end of the predetermined dwell time, the panels are scraped using a plastic Klean Strip[*] paint scraper (figure 4 and 5), and rinsed in deionized water.

2.5 Evaluations

The evaluations of the test panels were performed in the same way for both the manual and immersion experiments. Duplicate panels for each CARC version were prepared for each of the stripping products (tables 3–5). The amount of area of each layer of paint that was removed from the panels by the strippers was measured using a similar method described in ASTM standard D 1654 procedure B (*16*). The area exposed to the stripper is divided up into 100 smaller areas with the use of a grid printed on a transparent film. The grid is placed over the test area

[*]Klean Strip is a registered trademark of W. M. Barr & Company, Inc., Memphis, TN.

Table 3. Test matrix for round 1 of immersion tests.

Round 1 Immersion Experiment Test Matrix		
	Phosphated Steel Substrate	
	SB CARC 53022B/53039	WB CARC 53030/64159 Type 1
Product	Number of Panels	Number of Panels
RS #75	2	2
Greensolv 273D	2	2
Greensolv 274WL	2	2
Ardrox 2865	2	2
Gardostrip Q7900	2	2
PR-5044	2	2
HT-2263	2	2
Al Strip 49/AD 3030	2	2
CEM 483WW32	2	2
Al Strip 49	2	2
CEM 483WW23	2	2
Envirostrip #3	2	2
Envirostrip 1-S	2	2
Safety Strip 5896	2	2
Methylene Chloride/H2O	2	2

Table 4. Test matrix for round 2 of immersion tests.

Round 2 Immersion Experiment Test Matrix				
	Phosphated Steel Substrate (S)		Chromated Al Substrate (A)	
	SB CARC 53022B/46168		WB CARC 53030/64159 Type 2	
Product	Number of Panels		Number of Panels	
K-Chem III	2	2	2	2
Greensolv 274WL	2	2	2	2
Dip Strip	2	2	2	2
D-Zolve 298	2	2	2	2
D-Zolve 15-33LO	2	2	2	2
Safety Strip 5896	2	2	2	2
Envirostrip #3	2	2	2	2
HT-2263	2	2	2	2
Gardostrip Q7900	2	2	2	2
NPX	2	2	2	2

(figure 6) and the percentage of painted area removed is determined. The percent area removed of each layer of coating including the primer was recorded. The results of the two panels were averaged and the results were plotted.

Table 5. Test matrix for manual tests.

Manual Experiment Test Matrix				
Product	Phosphated Steel Substrate (S)		Chromated Al Substrate (A)	
	SB CARC 53022B/46168		WB CARC 53030/64159 Type 2	
	Number of Panels		Number of Panels	
Multi-Strip	2	2	2	2
ReadyStrip Hi-Perf.	2	2	2	2
Ultra-Strip	2	2	2	2
Ardrox 2865	2	2	2	2
Dorado 5051	2	2	2	2
D-Zolve 15-33LO	2	2	2	2
D-Zolve 3703	2	2	2	2
D-Zolve 1220GEL	2	2	2	2
Crest Strip #28	2	2	2	2

The immersion experiments were performed using the following two rounds of testing: (1) a screening round and (2) final down selection for full-scale trials. The test matrix for each can be found in tables 3 and 4, respectively. The first screening round was performed on MIL-C-53039 (single component CARC) and MIL-DTL-64159 Type II (two-component water-borne CARC) on steel substrates only. The steel test panels coated with these two versions of CARC were the easiest and quickest to produce in-house and were therefore used for the first screening round. Round 2, the final down selection round, included MIL-C-46168 (two-component solvent-borne CARC) and MIL-DTL-64159 Type I coated steel and aluminum samples. The majority of the U.S. Army's currently fielded systems are coated with the 46168 CARC, and many of them are constructed of aluminum. Therefore, it was considered prudent to include both MIL-C-46168 and aluminum substrate for the final down selection before full scale-up trials were performed.

3. Results

3.1 Immersion Stripping Experiments

A list of all the candidates, their manufacturer, and a brief list of characteristics can be found in table 1. All were used at full concentration with the exception of D-Zolve* 298 which requires the addition of 20–25% water prior to use. The immersion experiments were carried out in two rounds of testing. The results of the first round are displayed in figures 7–11. The data presented in figures 7 and 8 represent the performance of the listed strippers against MIL-C-53039 (figure 7) and MIL-DTL-64159 (figure 8). The actual product used at ANAD for immersion stripping is known as Pen-Strip NPX† manufactured by West Penetone. ARL did not receive this product in time to include it in round 1. However, it was suggested by ANAD that ARL include straight

*D-Zolve is a registered trademark of Solvent Kleene, Inc., Peabody, MA.

†Pen-Strip is a registered trademark of West Penetone, Inc., Villa D'Anjou, QC, CAN.

methylene chloride with a water “blanket” to reduce emissions. The straight methylene chloride was the only one in figures 7 and 8 that was tested at room temperature.

The coatings in round 1 were applied in the lab at ARL. The two CARC versions used in round 1 were selected because they were readily available and stocked in the lab and represented what was currently being applied at the depots. Note that the data in figure 8 represents the stripping performance of the HAP-free candidates against water-borne CARC MIL-DTL-64159 Type II. The Type II version contains a polymeric flattening compound rather than the silica found in the Type I. The images shown in figures 9–11 illustrate some of the effects the strippers had on the respective coatings in round 1. Each of these figures illustrates distinctly different effects of the strippers on the coatings, particularly with the 64159 Type II panels.

The second round of testing included the NPX product. The NPX formulation used at ANAD includes a wax layer to help reduce chemical emissions from the volatile methylene chloride and extend the tank life of the product. Figure 12 shows a sample of the product with the floating wax barrier layer. The NPX product performed as expected removing 100% of the coating within 30 min on all samples tested. Thus, the group photo in figure 13 showing all the NPX panels was deemed adequate to illustrate its effectiveness.

Round 1 did not produce an overwhelmingly strong candidate to be the “drop-in” replacement for the methylene chloride based products. For this reason, additional new products were solicited and investigated for round 2. The new products that were introduced in round 2 were: K-Chem CARC Stripper III, Dip Strip, D-Zolve 298, D-Zolve 15-33, and the baseline NPX product. Following the testing in round 1, only a limited number of the MIL-C-53039 coated test panels remained. Since this coating proved to be the biggest challenge in round 1, the remaining samples were used to test the additional new products and obtain the results in figure 14.

The vast majority of the U.S. Army’s legacy vehicles are currently coated with MIL-C-46168. Also, many of the vehicles, including all of the high-mobility, multipurpose, wheeled vehicles (HMMWV), bodies and parts are made from aluminum alloys. Therefore, before the final three candidates could be accurately down selected and recommended for full-scale trials, they must perform well against MIL-C-46168 and on chromated aluminum substrates. Round 2 includes these test panels along with those coated with MIL-DTL-64159 Type I water borne CARC. The results of these evaluations are shown in figures 15 and 16 (on steel substrates) and in figures 17 and 18 (on aluminum substrates).

To obtain a broad picture of the overall performance of the various strippers on the family of CARC coatings, the performance across all of the coatings regardless of the substrate is averaged and presented in figure 19.

3.2 Manual Stripping Experiment

The results of the manual stripping experiment can be seen in figures 20–23. The performance requirements for manual strippers were difficult to determine, particularly the dwell times.

ASTM D 6189-97 (*17*) required a dwell time of 30 min. Initial test (performed concurrently with the round 1 immersion tests) using only 30 min yielded no discernable results. Therefore, ASTM D 6189-97 was modified to allow for a longer dwell time that better reflected actual depot procedures. An adequate number of MIL-DTL-64159 Type II and MIL-C-53039 coated panels were not available to include in the manual tests because nearly all were consumed during the first round of immersion tests.

3.3 Pilot Testing Using Miscellaneous Parts

An assortment of used CARC-coated hardware was obtained from ANAD for the purpose of conducting some additional pilot tests using the top three performing HAP-free candidates, along with the baseline NPX. This hardware was mainly comprised of various brackets, hinges, covers, flanges, etc. An effort was made to sort these components into groups containing an equal number of each that was on hand. The experiment was carried out using the same process employed in the immersion panel experiments. The results for the component tests can be seen in figures 29–32. The amount of NPX remaining was not quite enough to fill the vat and completely immerse all of the components. Consequently, some areas of two of the components in figure 29 are still partially coated. There was a sufficient amount of all of the HAP-free candidates to completely immerse the parts in their vats.

4. Discussion

4.1 Immersion Tests, Round 1

In the first round of testing, only five of the HAP-free strippers, Gardostrip* Q7900, HT-2263, Envirostrip #3 and 1-S, and Safety Strip 5896 were effective on the MIL-C-53039 solvent-borne CARC system. As can be seen in figure 7, Gardostrip Q7900 clearly outperformed the others by removing nearly 55% of all the topcoat layers and more than 20% of the primer. The next best, Envirostrip #3, barely removed 5%, all of which was paint lifting at the edge of the panels (figure 9a). The straight methylene chloride was nearly twice as effective as the Gardostrip Q7900 removing 90% of the entire MIL-C-53039 coating system including the epoxy primer. The only noticeable effect on the panels by RS #75, Greensolve 274WL, Alstrip/AD3030, CEM 483WW32, Al Strip 49, and CEM 483WW23, was some color fading similar to that seen in figure 9a.

Significantly different results were observed for some of the alternatives on the MIL-DTL-64159 Type II waterborne CARC coating. For all but three of the HAP-free strippers, the MIL-DTL-64159 Type II was considerably easier to remove. Figure 8 shows that Greensolv 274WL, Gardostrip Q7900, HT-2263, Envirostrip #3 and 1-S, and Safety Strip 5896 all performed better than even the straight methylene chloride on the water-borne Type II CARC

*Gardostrip is a registered trademark of Chemetall Chemical Products, Berkeley Heights, NJ.

system (see figures 9b, 10b, 11b). It can be seen in figure 9 that, although the Envirostrip #3 had a minimal effect on the MIL-C-53039 (figure 9a), it was able to remove all of the 64159 Type II coating (figure 9b). The Envirostrip #3 seems to break the bond of the coating at the substrate, leaving the released coating almost completely intact. This phenomenon was typical for the 64159 Type II reacting to many of the strippers, indicating that water-borne Type II CARC remains more flexible. The performance of the Gardostrip Q7900 (figure 10) was very similar to that which was found in a previous study by Penn State's Applied Research Laboratory (*18*). Much of this removal occurred within the first 10 min, indicating that perhaps agitation of the vats would enhance the strippers effectiveness. The inability of RS #75 Alstrip/AD3030, Al Strip 49, and both CEM 483WW23 and CEN 483WW32 to penetrate this seemingly easily strippable coating prevented them from moving beyond the first round.

4.2 Immersion Tests, Round 2

Based on the results of round 1, only the top HAP-free candidates were down selected to the top candidates to move on to round 2. In addition, four new products: K-Chem CARC Stripper III, D-Zolve 298, D-Zolve 15-33, and Dip Strip were added to the round 2 test matrix. The Pen-Strip NPX, which was not available in round 1, was also included as the baseline. The data presented in figure 14 are a compilation of the results of round 1 and 2 testing on MIL-C-53039 on steel substrate. Here it can be seen that two of the new candidates (K-Chem III and D-Zolve 298) performed well. In fact the K-Chem product matched the performance of the Pen Strip NPX removing 100% of all layers in 30 min. The D-Zolve 298 also performed well, removing 90% of the topcoat and more than 65% of the epoxy primer. These two products were not tested on the MIL-DTL-64159 Type II with polymeric beads. However, given the results in round 1, MIL-C-53039 is considered a more difficult coating to remove using HAP-free strippers. Therefore, it is expected that if the stripper can remove the MIL-C-53039, then it is likely that it will remove the MIL-DTL-64159 Type II.

Figures 15–18 represent all new results from round 2. The ability of the immersion strippers to remove MIL-DTL-64159 Type I from steel substrates is shown in figure 15, while the ability to remove MIL-C-46168 from steel is shown in figure 16. By comparing figures 15 and 16, it can be seen that the HAP-free strippers, as a whole, had more success removing MIL-C-46148 than MIL-64159 Type I. That is, the solvent-borne system was easier to remove than the water-borne system. That is contrary to what was seen in round 1 of testing where the water-borne MIL-DTL-64159 Type II was considered easier to remove than the solvent-borne MIL-C-53039. This is evident when comparing figure 10 with figure 24. One possible explanation for this phenomenon may be that the polymeric beads in the Type II system enabled the stripper to be absorbed more readily. Nevertheless, the K-Chem III and the D-Zolve 298 equaled the performance of the NPX on both the MIL-64159 Type I and MIL-C-46168 systems. Moreover, on the MIL-C-46168 only one product, Dip Strip, failed to remove at least 40% of the entire coating system.

Figures 17 and 18 show the same two CARC systems on a chromated aluminum 2024 substrate. The aluminum data in figures 17 and 18 demonstrate a similar performance trend as with the steel substrate data in figures 15 and 16. K-Chem III and D-Zolve 298 performed best on the MIL-DTL-64159 Type I. Once again, several HAP-free strippers performed well on the MIL-C-46168. Along with the K-Chem III and D-Zolve 298, Safety Strip 5896, Envirostrip #3, and Gardostrip Q7900 all removed more than 90% of the entire coating system, including the epoxy primer.

The average of all of the panels for each of the candidate strippers tested in round 2 was taken to determine their performance independent of the CARC version being stripped. It can be seen from figure 19 that of the eight nonmethylene chloride strippers, only three achieved more than 65% paint removal, with two of those being over 90%. More importantly, figure 19 shows that the K-Chem III (figure 25) product maintains the same stripping effectiveness as the methylene-chloride-based NPX (figure 13).

4.3 Manual Tests

The results from the manual stripping experiments are presented in figures 20–23. The Crest Strip #28 performed the best overall, removing the majority of all layers from the chromated aluminum panels and nearly 40% of the three layers of top coat from the steel panels. The Crest Strip #28 began blistering the paint within 5 min after application (figure 27). The D-Zolve 1220GEL showed blistering of the 46168 panels at about 30 min. Figure 28 shows a picture of the panels 40 min after stripper was applied. Although the lifting looks significant, only the top layer of the MIL-C-46168 was removed. Ardrox[*] 2865 and Dorado[†] 5051 also showed signs of peeling early on the MIL-C-46168 samples, but also didn't manage to penetrate beyond the first layer. Each product, when applied to the MIL-DTL-64159 Type I coating, seemed to dry out relatively fast, as opposed to when applied to MIL-C-46168, which seemed to stay moist throughout the test. The reason for this has not yet been confirmed. However we could speculate that these differences in "drying rates" could be related to differences in the surface energies.

It is evident, given the resources and limited boundaries of this experiment, that none of the HAP-free strippers performed adequately on MIL-DTL-64159 Type I CARC. In fact, none even penetrated the top layer of coating. Regardless of the substrate, the HAP-free strippers were completely ineffective on the MIL-DTL-64159 Type I CARC.

4.4 Stripping of Miscellaneous Parts

The stripping of the miscellaneous parts was conducted to obtain a sense of how the top HAP-free candidate strippers would perform on actual materiel. The version and type of CARC paint on these parts is unknown. Therefore, the results presented in figures 29–32 are considered

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[*]Ardrox is a registered trademark of Chemetall Chemical Products, Berkeley Heights, NJ.

[†]Dorado is a registered trademark of Eldorado Chemical Company, Inc., Indianapolis, IN.

anecdotal. As expected, the NPX product removed all of the paint that was immersed from all of the parts cleanly. Although the D-Zolve 298 product left some paint behind, it also left the metal surface with a bright, clean appearance. On the other hand, like the NPX, the K-Chem product removed all of the paint from all of the parts. Of some concern though, may be the residual corrosion products left behind by the K-Chem CARC Stripper III. This may add an extra step for removing the corrosion in the refinishing process. Of the three HAP-free strippers tested on the parts, Gardostrip left the most paint on the parts. These results, although anecdotal, are in agreement with the panel results previously discussed. That is, consider the data in figure 19 for the overall immersion stripping performance. From this, one may expect that K-Chem III would be the most effective, D-Zolve 298 next, and Gardostrip third.

5. Conclusions and Recommendations

Benzyl alcohol-formic acidic strippers were the most effective HAP-free product for removing the different CARC formulations against which they were tested. The D-Zolve 298 and K-Chem CARC Stripper III, with a reported PH of 2, when heated to approximately 160 °F, can achieve similar stripping performance to that of the NPX. Based on this performance alone, both can be a viable alternative to the current immersion processes involving methylene-chloride-based substances. However, the low PH of these strippers should be carefully considered when being used on materials known to be susceptible to hydrogen embrittlement, such as high-strength steels.

The two-component, solvent-borne MIL-C-46168 was not as resistant to the non-methylene chloride HAP-free strippers as the MIL-C-53039 and MIL-DTL-64159 Type I CARC versions. Since MIL-C-46168 has been in use since the early 1960's, the vast majority of the U.S. Army legacy vehicles are presently coated with it. Therefore, a HAP-free stripper for the immersion process can be used in place of methylene chloride products with little or no reduction in throughput. However, a toxicity evaluation by the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) should be completed before permanent implementation is considered.

The success of many of the HAP-free strippers on the water-borne MIL-DTL-64159 Type II with polymeric beads suggests that a broader use of this CARC version, in the long run, will help maintain shorter strip times while enabling the U.S. Army depots to remain in compliance with the new NESHAP regulations, as well as provide a wider selection of the HAP-free strippers that are currently commercially available.

Given the boundaries of the manual stripping experiment, none of the HAP-free strippers tested proved to be even slightly effective at removing the MIL-DTL-64159 Type I CARC. For manual stripping under ambient conditions, only the methylene chloride-phenol Crest #28 had

any impact on the Type I water-borne system. For this reason, no HAP-free alternatives can be recommended for use on this paint at this time under these conditions.

Several of the HAP-free strippers were successful at removing at least some portion of the top layer of the MIL-C-46168, but were not able to penetrate beyond that with only one application. In fact, the D-Zolve 1220 GEL nearly matched the performance of the methylene chloride-phenol Crest #28 on the painted steel substrate. For many of the legacy vehicles coated with the MIL-C-46168, the D-Zolve 1220GEL may be a viable alternative to Crest #28. However, multiple applications of the product will be necessary to be completely successful.

6. Summary/Future Work

Although this effort focuses on the task of identifying and evaluating HAP-free alternative paint strippers as a potential replacement for methylene chloride, it is understood that maintaining the level of productivity at the U.S. Army depots is an important consideration. The work presented here is part of an ongoing effort to identify and qualify the alternatives and more work is planned for the coming months. In addition to continuing a search for better products, materials compatibility, and toxicity examination by CHPPM, as well as scale-up trials, are planned for some of the products evaluated in this report.

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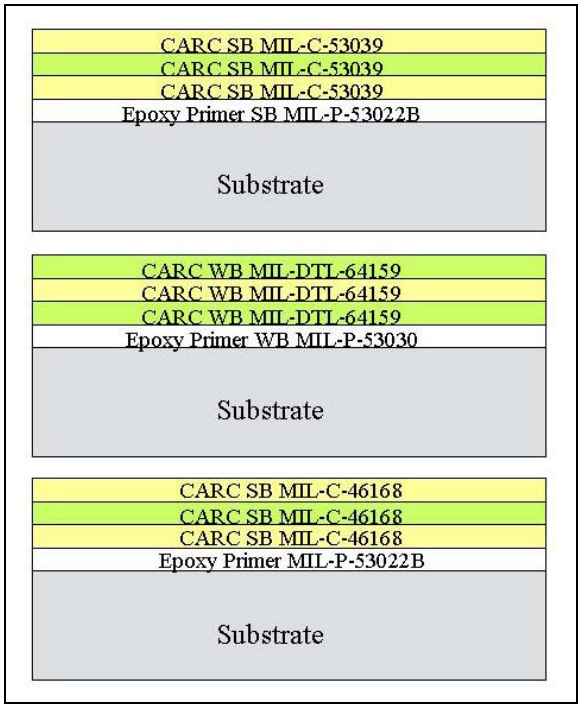


Figure 1. Paint layering systems used to enable easier stripping evaluations.

Figure 2. Immersion process “mini” vat setup with thermocouples. The horizontal stainless steel bars shown are for supporting the test panels when immersed.

Figure 3. Panels awaiting manual application.

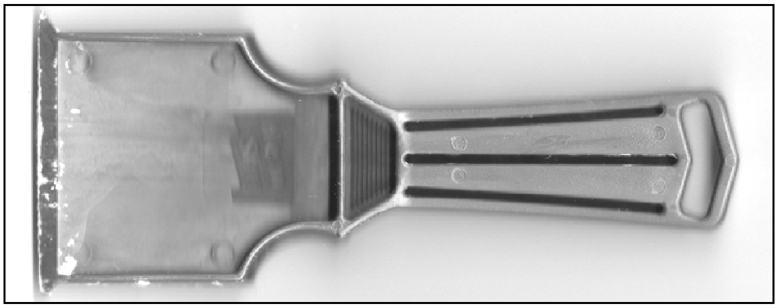


Figure 4. Plastic Klean Strip paint scraper used for scraping in the "manual" paint-stripping process.

Figure 5. Scraping operation in the manual stripping experiment. A bucket of water was used to capture the debris for disposal. A separate bucket of deionized water was used for rinsing.

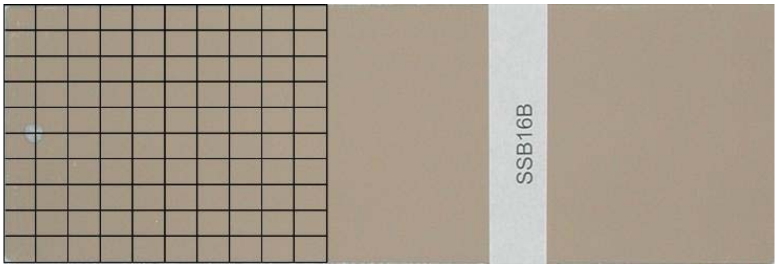


Figure 6. Example of a CARC-coated test panel with overlayed evaluation grid. The grid is commonly used rating corrosion panels according to ASTM 1654 Procedure B.

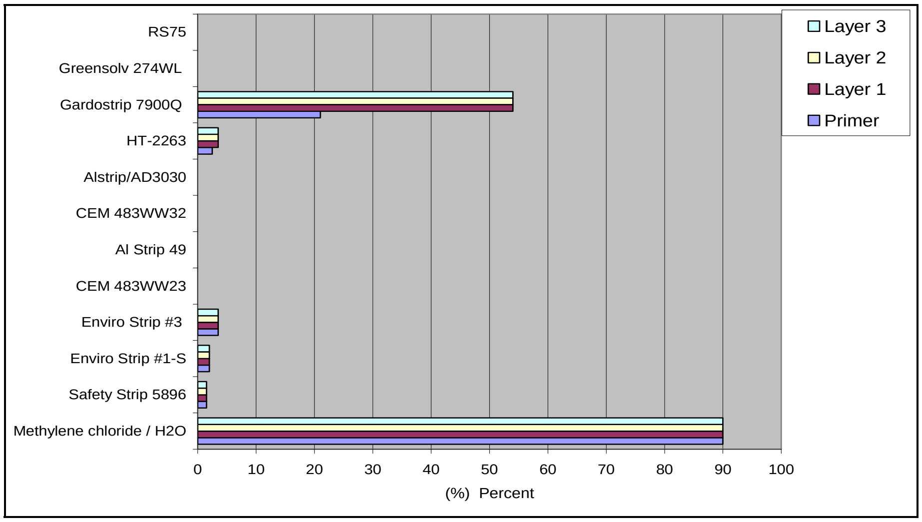


Figure 7. Round 1: percentage of MIL-C-53039 CARC removed from steel substrate after 30-min immersion.

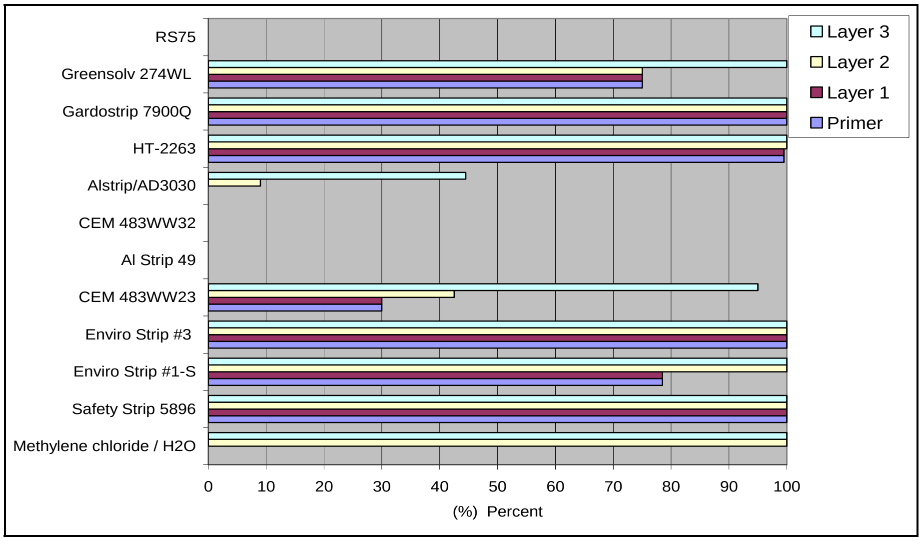


Figure 8. Round 1: percentage of MIL-DTL-64159 water-borne CARC removed from steel substrate after 30-min immersion.

(a) (b)

Figure 9. MIL-C-53039 CARC (a), MIL-DTL-64159 Type II CARC (b), both shown after 30-min immersion in Envirostrip #3. Several HAP-free alternatives performed well on the waterborne CARC, while MIL-C-53039 presented more of a challenge.

(a) (b)

Figure 10. MIL-C-53039 CARC (a), MIL-DTL-64159 Type II CARC (b), both shown after 30-min immersion in Gardostrip Q7900.

(a) (b)

Figure 11. MIL-C-53039 CARC (a), MIL-DTL-64159 Type II CARC (b), both shown after 30-min immersion in straight methylene chloride.

Figure 12. Example of the methylene-chloride-based NPX chemical stripper. Note the floating wax layer that is necessary to reduce chemical emissions.

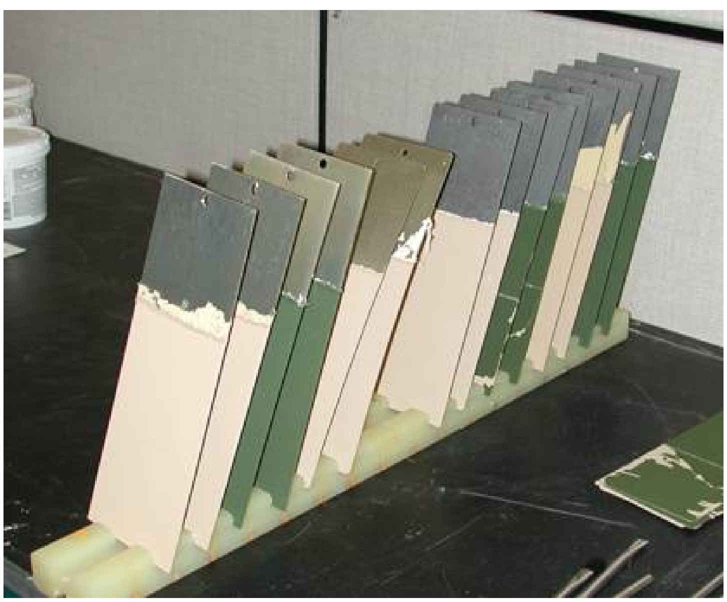


Figure 13. Depicts the effectiveness of the NPX stripper on all of the CARC-coated panels.

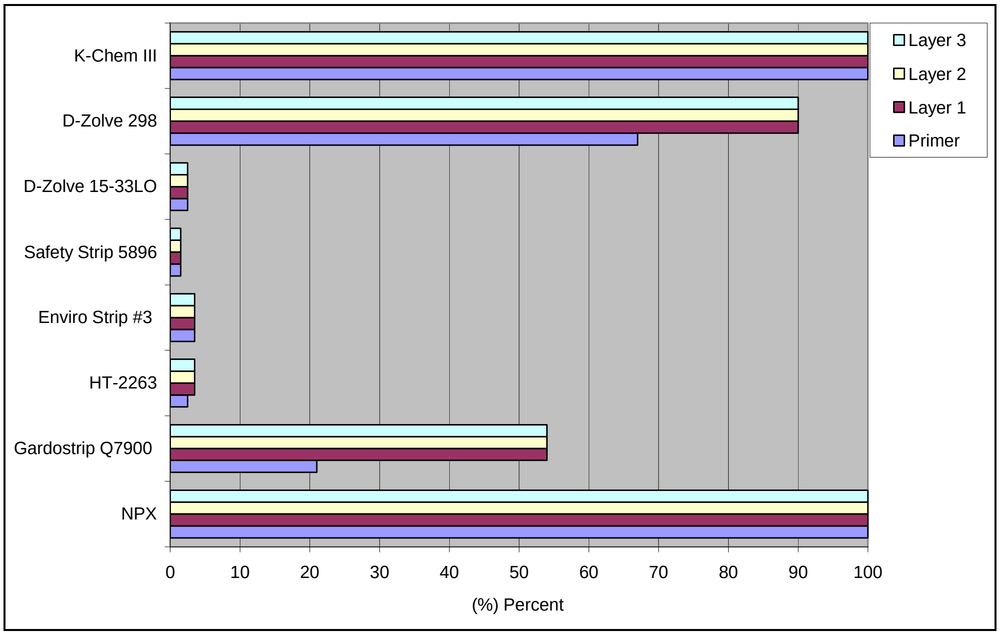


Figure 14. Round 2: percentage of MIL-C-53039 single component solvent-borne CARC removed from steel substrate after 30-min immersion.

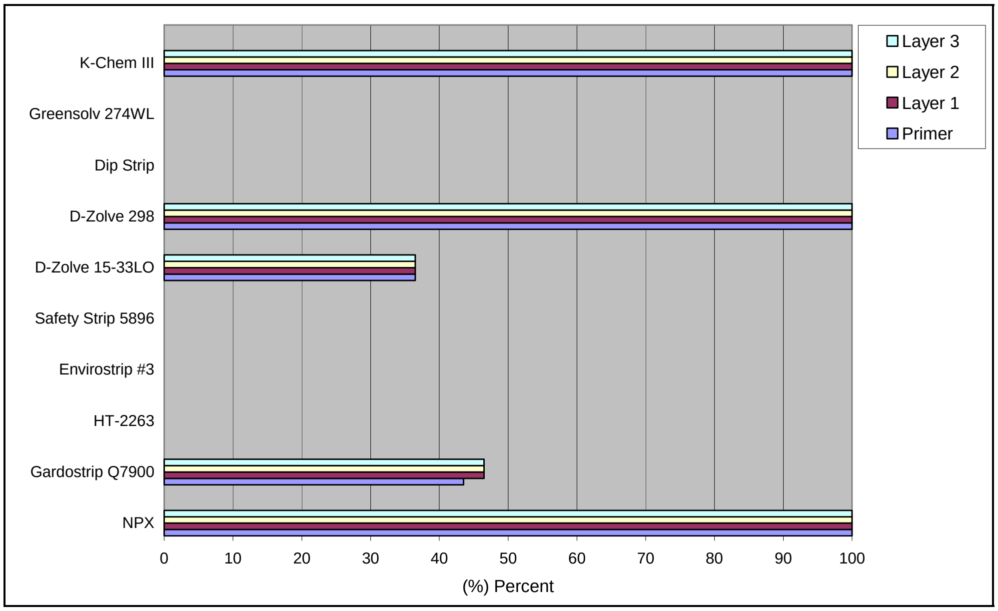


Figure 15. Round 2: percentage of MIL-DTL-64159 water-borne CARC removed from steel substrate after 30-min immersion.

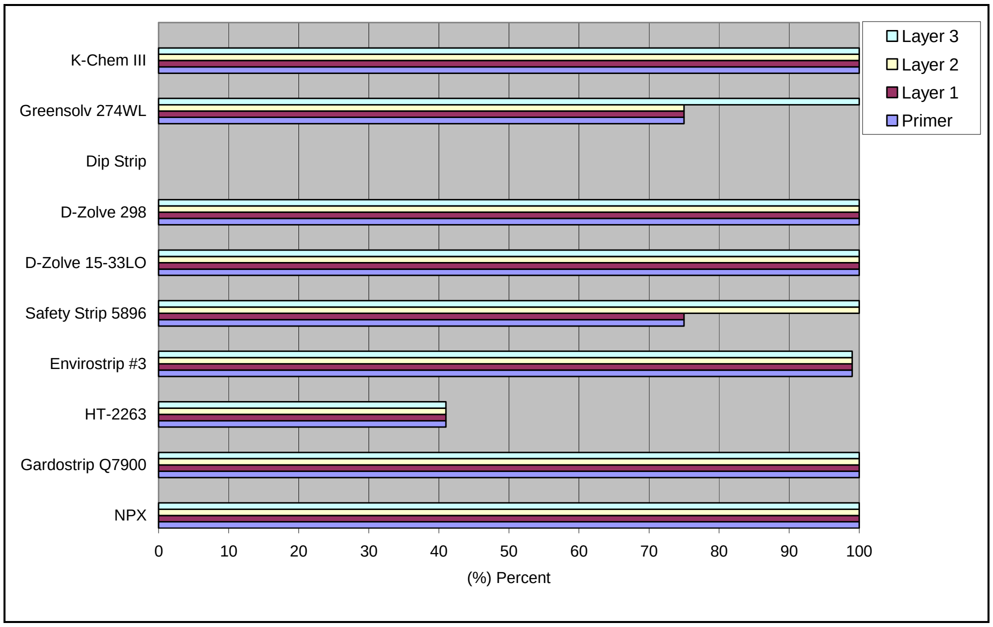


Figure 16. Round 2: percentage of MIL-C-46168 two-component solvent-borne CARC removed from steel substrate after 30-min immersion.

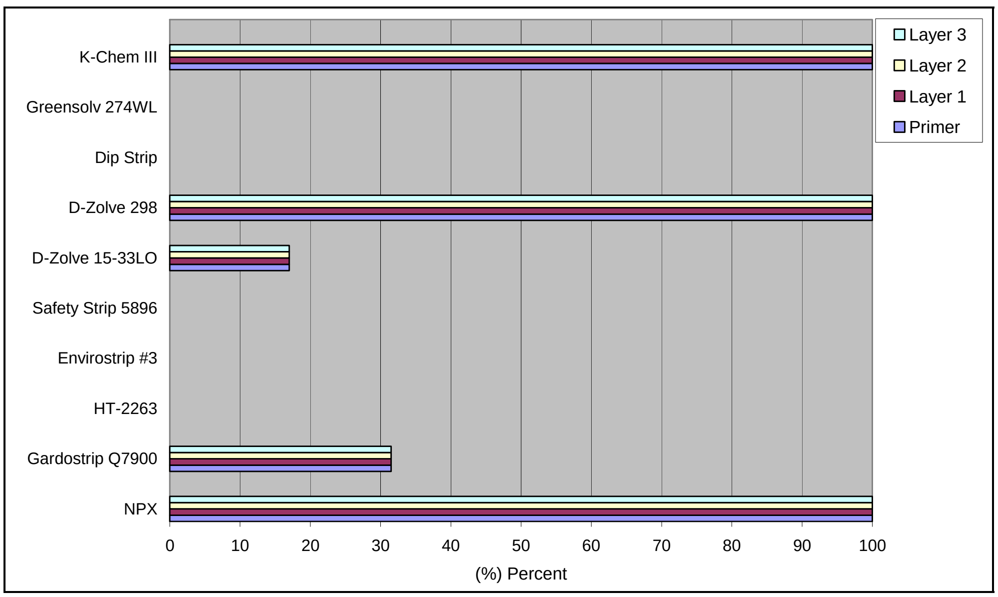


Figure 17. Round 2: percentage of MIL-DTL-64159 water-borne CARC removed from aluminum substrates after 30-min immersion.

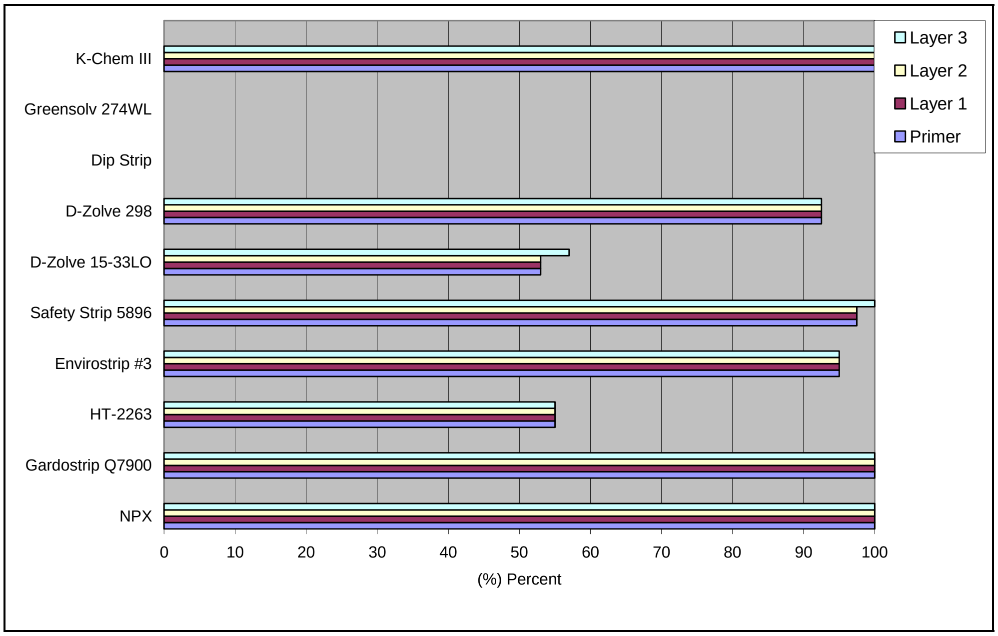


Figure 18. Round 2: percentage of MIL-C-46168 two-component solvent-borne CARC removed from aluminum substrate after 30-min immersion.

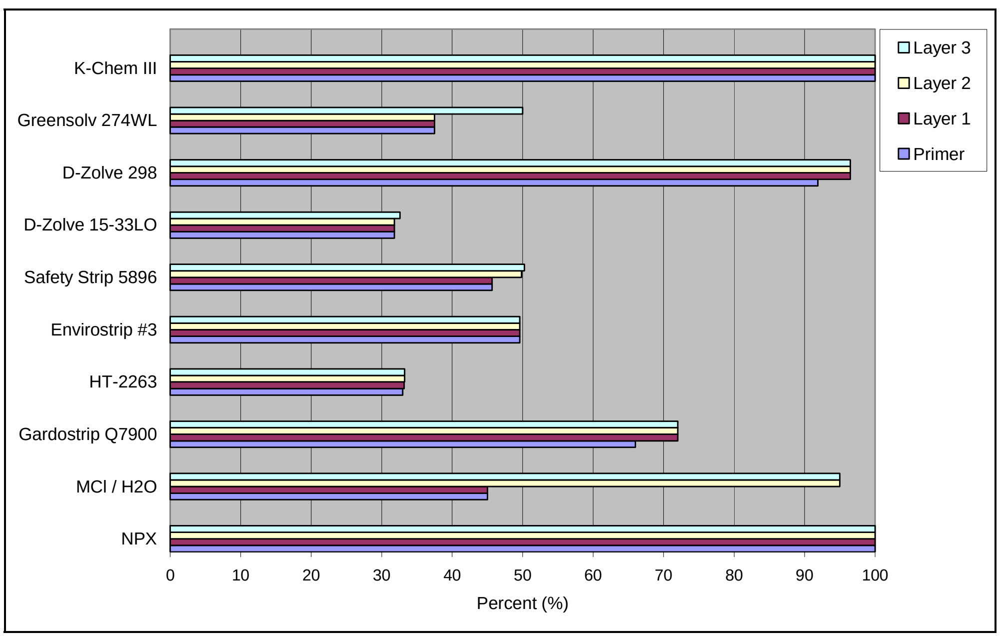


Figure 19. Overall immersion stripping performance averaged across all CARC versions regardless of substrate.

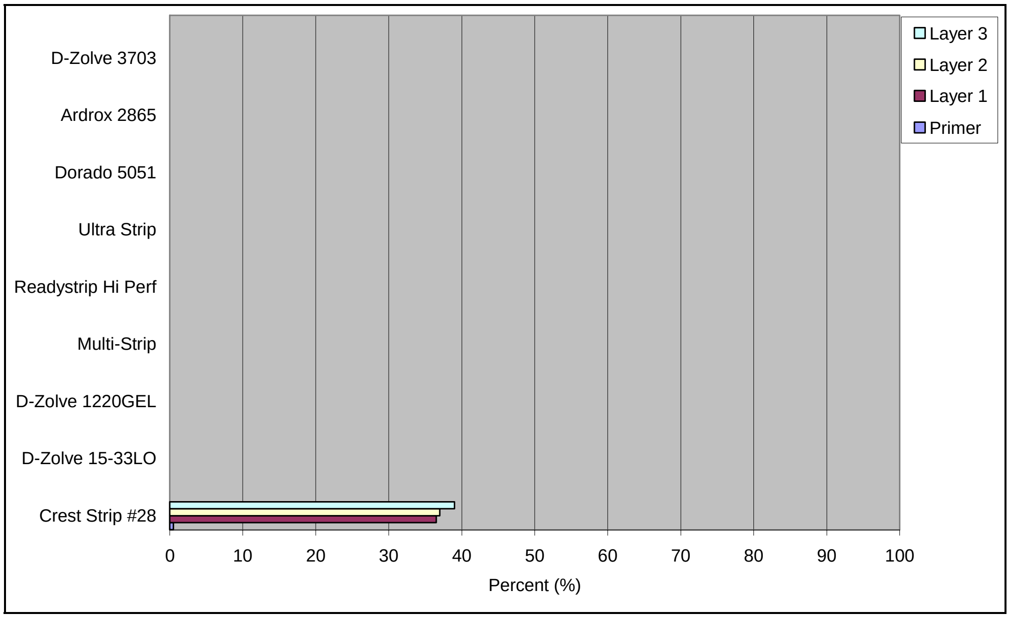


Figure 20. Percentage of MIL-DTL-64159 Type I water-borne CARC removed from steel substrate using manually applied (brush-on) paint-stripping candidates.

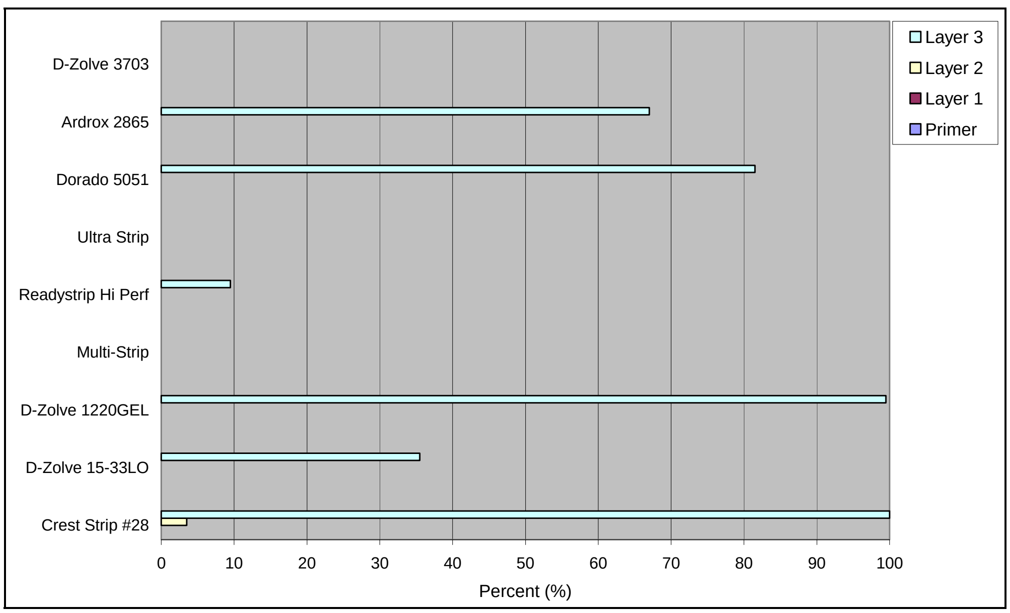


Figure 21. Percentage of MIL-C-46168 solvent-borne CARC removed from steel substrate using manually applied (brush-on) paint-stripping candidates.

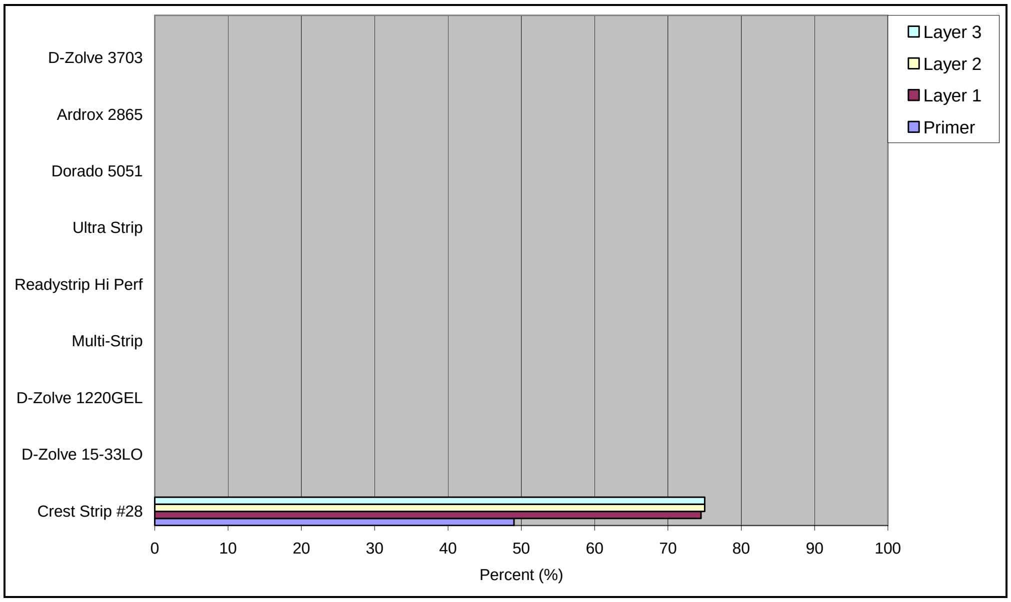


Figure 22. Percentage of MIL-DTL-64159 Type I water-borne CARC removed from aluminum substrate using manually applied (brush-on) paint-stripping candidates.

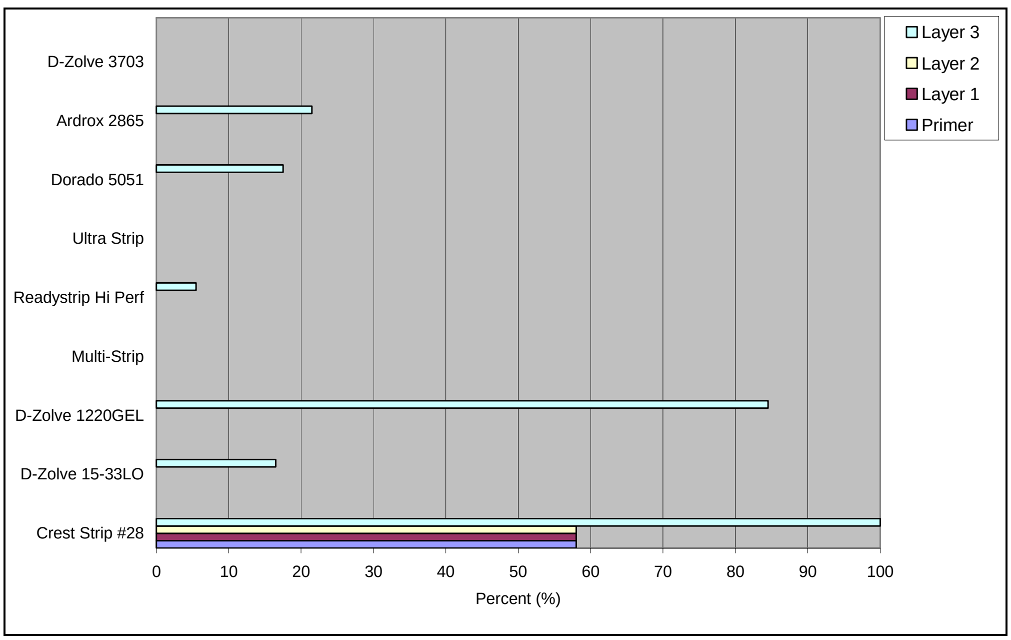
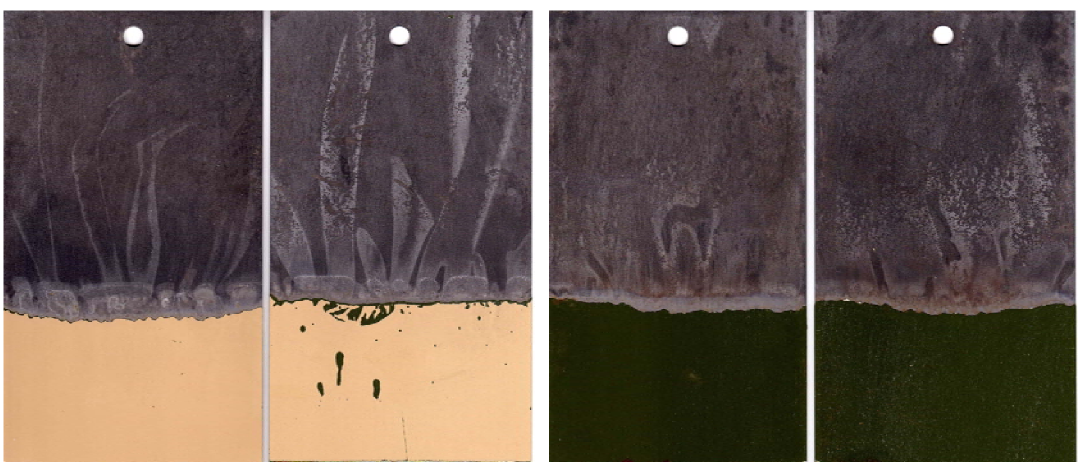


Figure 23. Percentage of MIL-C-46168 solvent-borne CARC removed from aluminum substrate using manually applied (brush-on) paint-stripping candidates.

ROUND 2 IMAGES

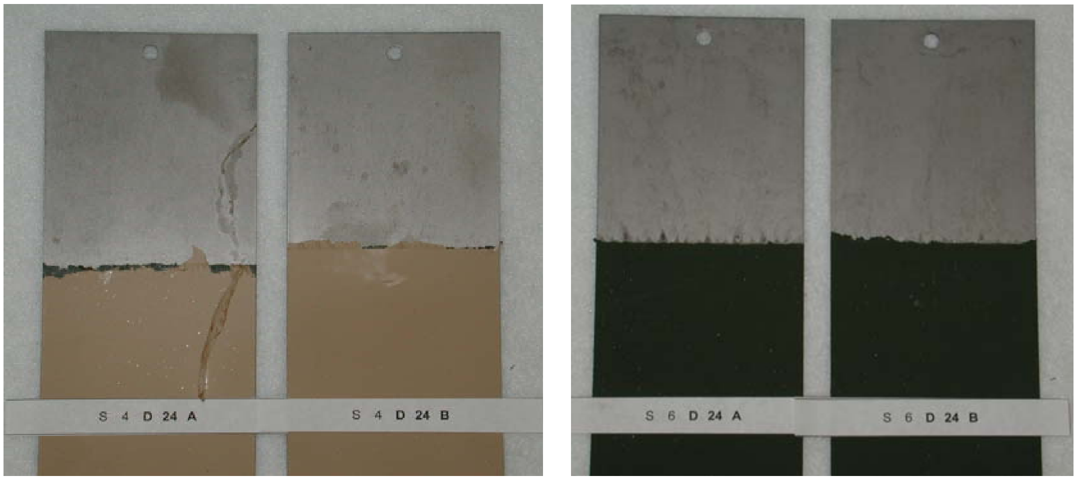
(a) (b)

Figure 24. MIL-C-46168 CARC (a), MIL-DTL-64159 Type I CARC (b) on steel substrate, both shown after 30-min immersion in Gardostrip Q7900.



(a) (b)

Figure 25. MIL-C-46168 CARC (a), MIL-DTL-64159 Type I CARC (b) on steel substrate, both shown after 30-min immersion in K-Chem CARC Stripper III.



(a) (b)

Figure 26. MIL-C-46168 CARC (a), MIL-DTL-64159 Type I CARC (b) on steel substrate, both shown after 30-min immersion in D-Zolve 298.

(a) (b)

Figure 27. Crest Strip #28 began to lift the MIL-C-46168 within 5 min after application (a) and after 1.5 hr, all of the top layer was removed and some spots were removed down to the substrate (b).

(a) (b)

Figure 28. The D-Zolve 1220GEL began to show signs of paint lifting at about 40 min after application on MIL-C-46168 (a). The panels after the 1.5-hr dwell time (b). Nearly all of the first coating has been removed from panel a and about 90% of panel b.

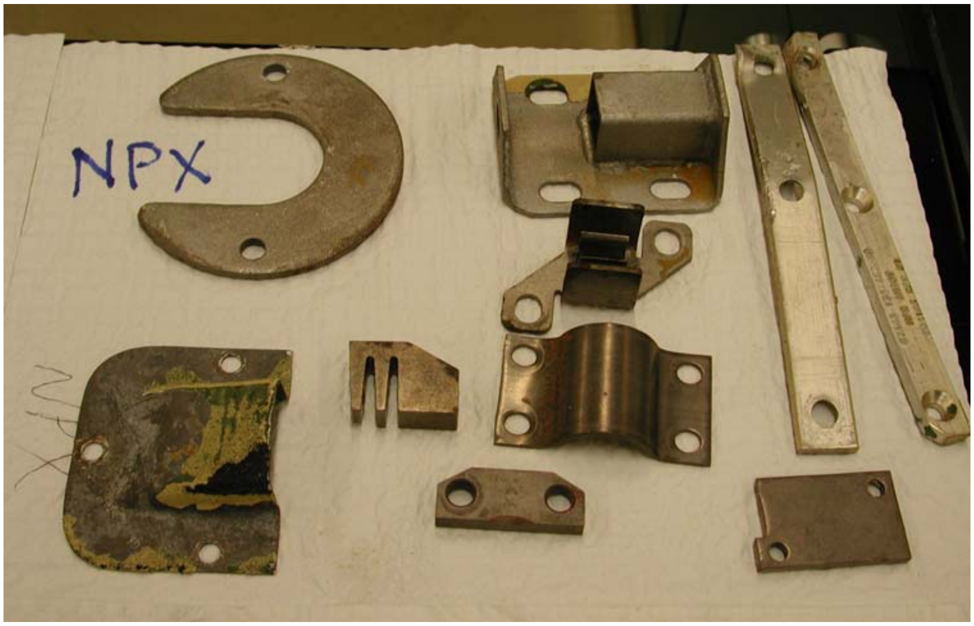


Figure 29. Stripping of miscellaneous parts after 30-min immersion in the baseline Pen-Strip NPX. Nearly 100% of the paint was removed.

Figure 30. Stripping of miscellaneous parts after 30-min immersion in K-Chem CARC Stripper III. One hundred percent of the paint was removed; however, some light corrosion on the steel parts was generated.

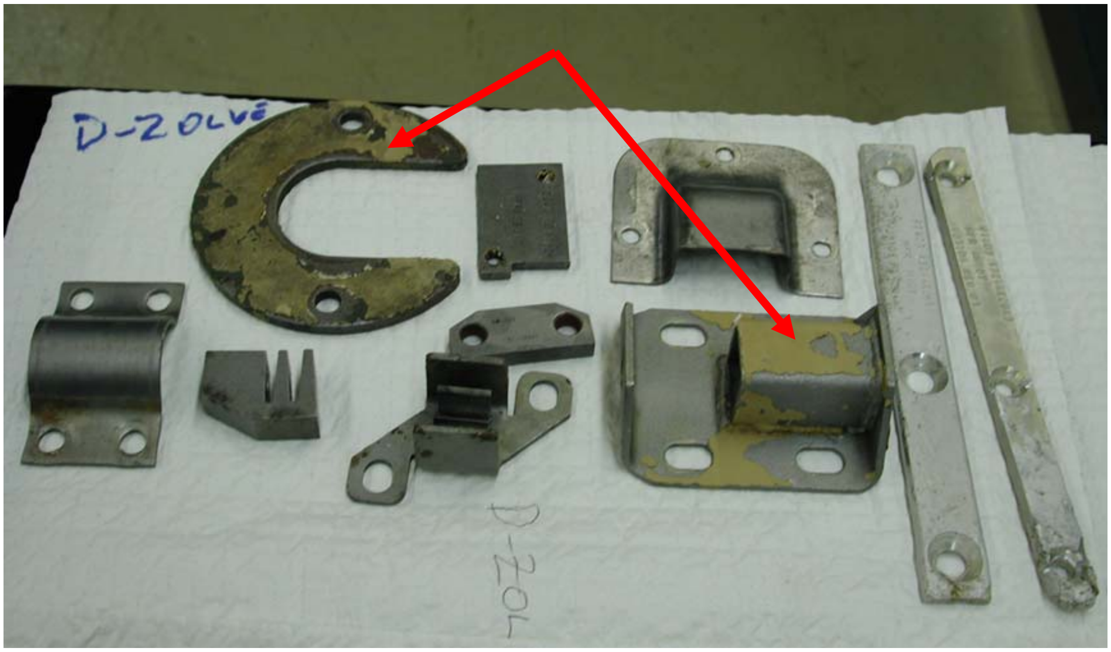


Figure 31. Stripping of miscellaneous parts after 30-min immersion in D-Zolve 298. With the exception of the two parts shown (see arrows), all of the paint was removed, and parts were free of corrosion. Paint was left on only one side of the C-flange (shown).

Figure 32. Stripping of miscellaneous parts after 30-min immersion in Gardostrip Q7900. A significant amount of paint remained, but parts were free of corrosion. One hundred percent of the paint was removed from one side of the C-flange.

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